Simple Swing Model

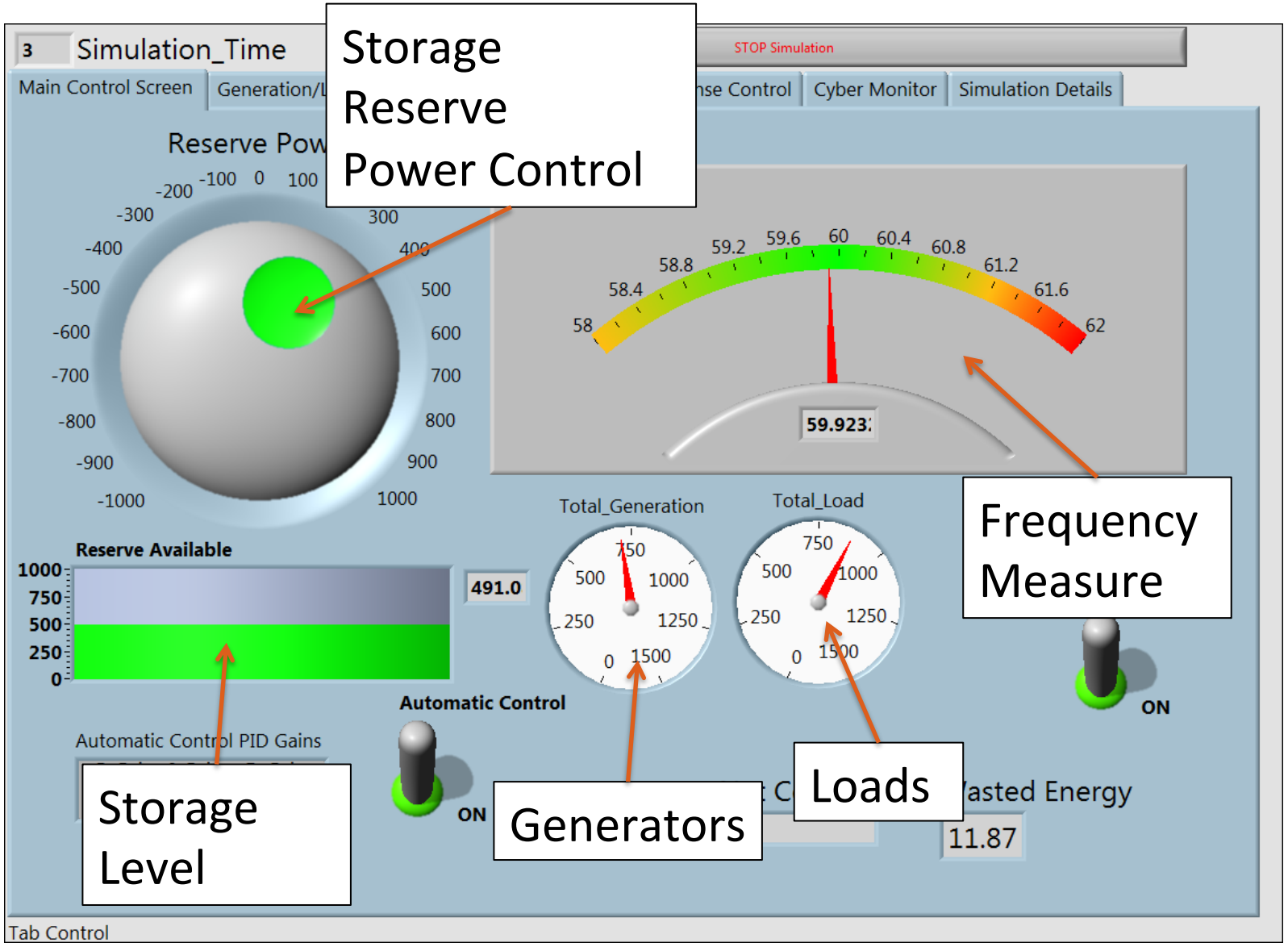
Micro-grid simulator:
The Grid
Control Systems
A window into the need for Resilient Control Systems

Questions? Contact Tim McJunkin (tim@mcjunkin-web.org)

Introduction

- A model emulating a small grid that can run isolated or connected to external generation
- Let's students have a platform to work with when away from Microgrid in a box
- Keeping it simple: neglect reactive power
- A tool for students to understand basics of:
  - Real Power Balance on Frequency of electric grid
  - Control and automatic control loops
  - Complexity in control systems
  - A motivations to Resilient Control Systems study

What's in the Model



Frequency of the Grid

- Full scale generators are massive spinning machines.
- Alternating current occurs as windings and/or magnets spin past each generating electric power.
- Designed to spin at rate that generates 60Hz AC wave forms.
- Kinetic energy/momentum helps regulate this frequency.

Hoover Dam Generators

Source: http://commons.wikimedia.org/wiki/File:Hoover_Dam's_generators2.jpg

A little math: Swing Equation

- $P_g - P_l = J\,\omega_m \left(d\omega_m / dt \right)$ – Grainger/Stevenson

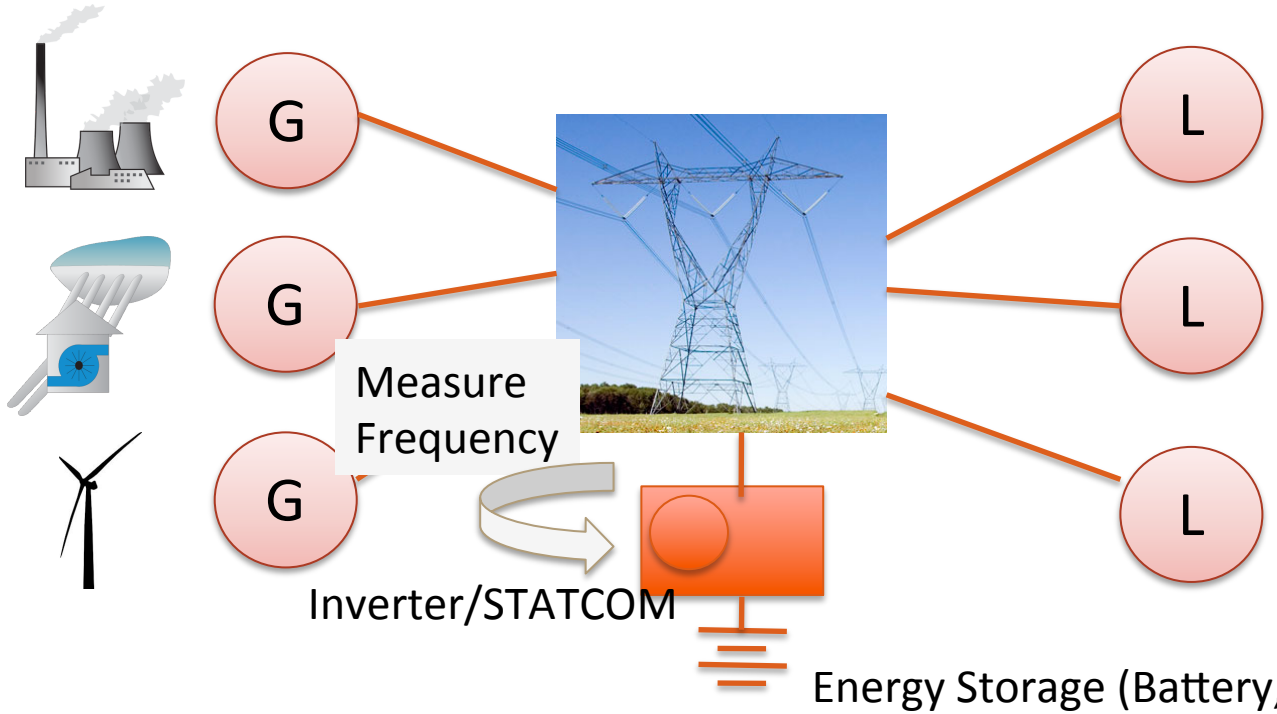
Approximately:

- $\Delta\omega_m \approx \dfrac{(P_g - P_l)\,\Delta t}{J\omega_m}$

- What it means:
  - Gen bigger than Load = Frequency ↑
  - Load bigger than Gen = Frequency ↓
  - Bigger J slower the change
- Frequency deviates too much machines break!!! http://consultkirby.com/files/TM2003-41_Freq_Control.pdf

Balancing Power

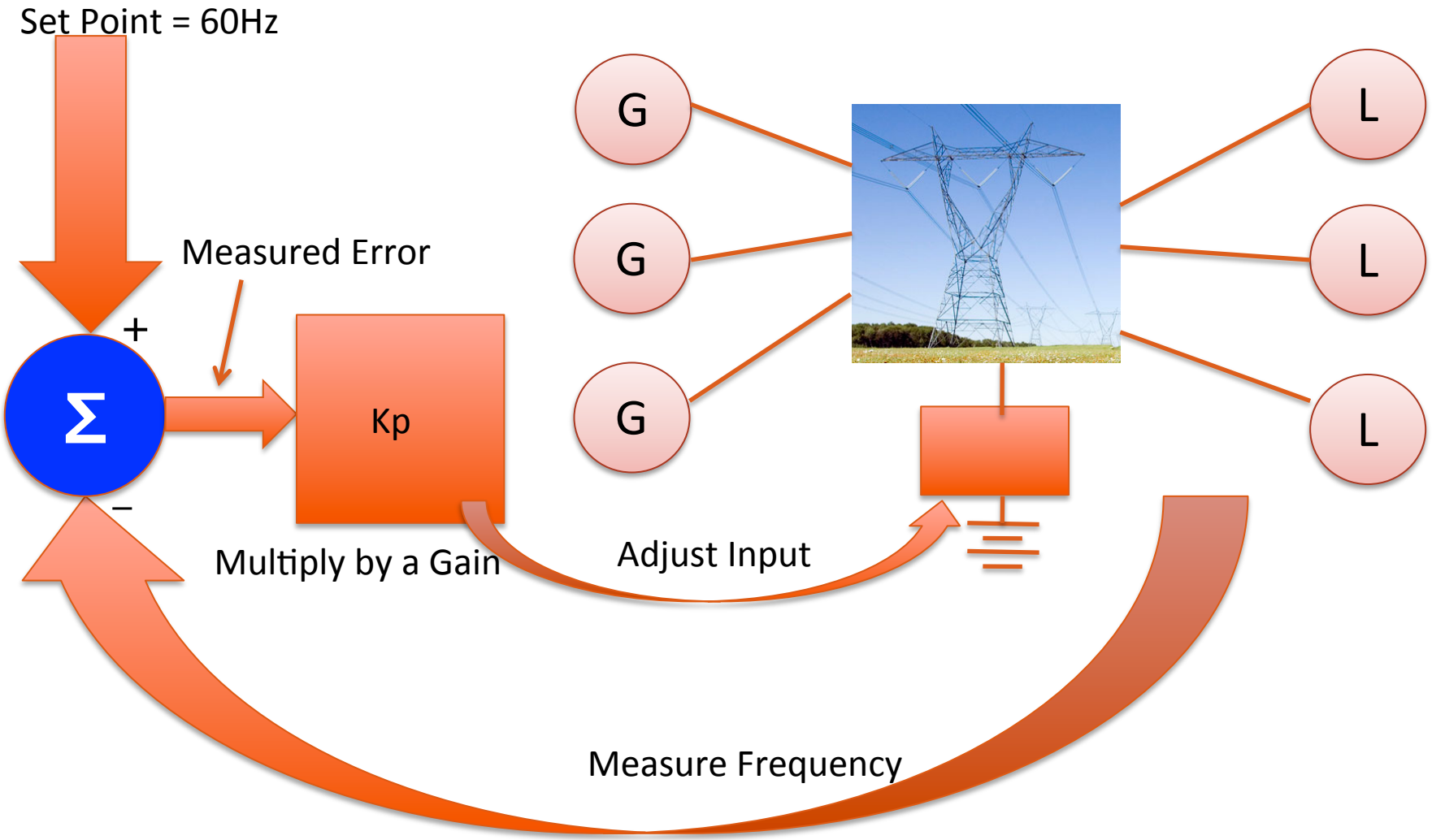
- Generation and Loads will change over time
- Add a storage device with an inverter to have a easy control input
- Measure Frequency and adjust input from Storage



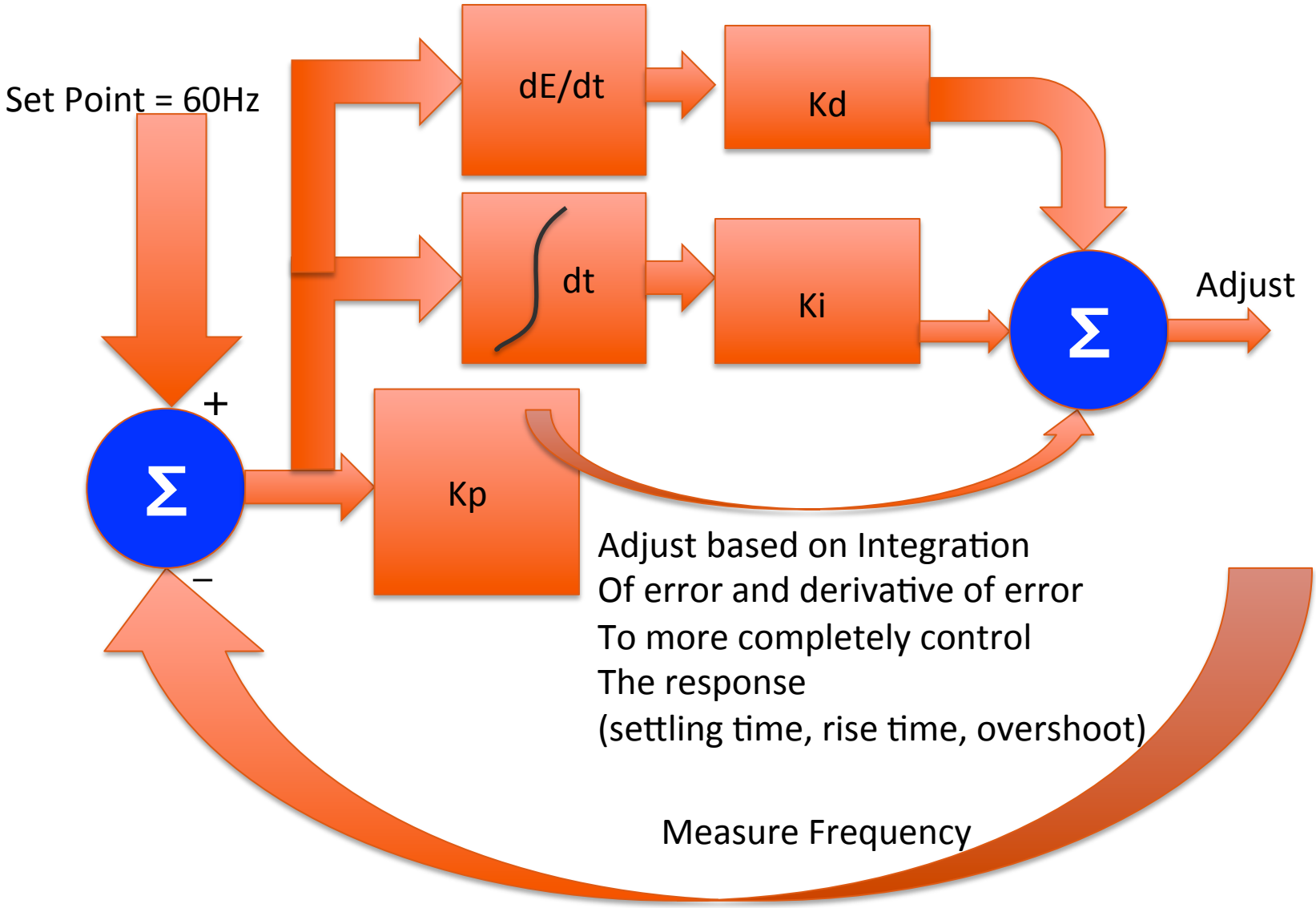
Feed Back

- Measure Frequency adjust control input from Storage
  - Try it manually. Turn on the model and turn off automatic control and adjust the knob yourself.
  - When you get tired of this – and you will turn automatic control back on.
  - Try adjusting the PID gains on the control loop.

Feedback Loops



What are the other gains



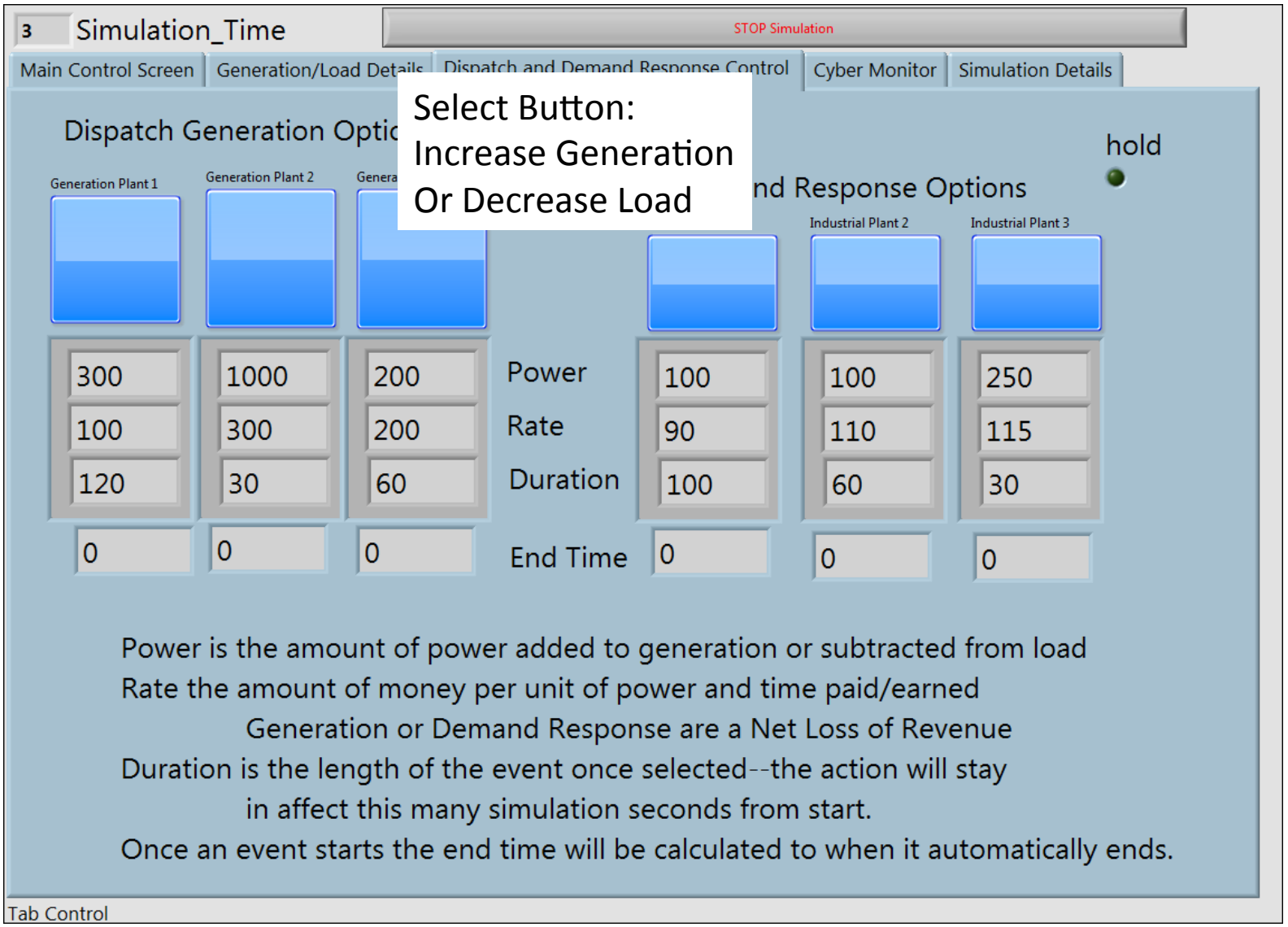
Save some money--Fire the Operator??

- NO!
- The low level controls need to respond quickly and persistently – a very monotonous job for a person.
  - Let people do higher level decision making
  - And monitor, predict and respond to events
- Next level up… monitor energy Storage
  - Low level Automatic Control only works if controls are not to their limits (Saturation—out of stored energy)

Human in the Loop

- What can be done at the next level?
- Simulator has another tab for asking for more generation or cutting load (dispatch generation or demand response)
- Ordering more Generation Costs Money
- Demand response also Costs Money – Customer not charged for Energy not delivered
- Operators may be tasked with keeping the grid up and trying to do it with least expense as possible.
- Give it a try in the model.

Dispatch and Demand Response



Even Higher Level Supervision

- Negotiate contracts or use energy markets to advantage
- Analyze and decide on new generation assets and balance of types of generation with storage capabilities
  - The model has advanced settings to allow you to choose how much wind versus hydro power. Why might this matter?
- Manage contingency plans and communicate with other connected grid operators to avoid “big badness”

Needs of Resilient Control System in a Grid

- Complex system Multi-levels
  - Want efficiency and high performance
  - …but with graceful degradation and quick recovery from upset
  - Maintain margin to maneuver[1] to avoid cascading and catastrophic failures – East Coast Blackout
  - Powers other critical infrastructure
- Distributed system and computer control lead to threat of cyber and physical attacks

1. http://www.ndia.org/Divisions/Divisions/HumanSystems/Documents/David%20Woods.pdf

Resilience Control (continued)

- Large number of data sources
  - Need for Data Fusion to provide:
    - The right information
    - To the right person/people
    - At the right time
- Mixed Human/Machine Initiative
  - Understanding how the system, automation and humans in the loop interact
  - Better designs and outcomes

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  - Better designs and outcomes
- Agents and automation at various levels and scales (temporal, spatial, and magnitudes)

Getting Started with SSM

- Module and assignments at Canvas Site with instructions for installing and initial exercises
  - https://canvas.instructure.com/courses/808568/modules/items/5106840
- Model is written in Labview 2011. Source code can be made available on request. tim@mcjunkin-web.org
- Could be used as a platform to further explore Resilience or other areas of study.